

HYBRID CHARGE COUPLED CMOS IMAGE SENSOR

TECHNICAL FIELD

[0001] The present invention relates to image sensors and more particularly to a CMOS image sensor that uses charge coupled technology to implement frame memory.

BACKGROUND

[0002] Image sensor technologies fall into two main categories: charge coupled devices (CCD) and CMOS image sensors. The advantages of each have been well documented. For example, CMOS image sensors have advantages with respect to power consumption, manufacturing costs, and circuit integration. Still, CCDs maintain advantages in certain high-end applications.

[0003] There have been attempts to integrate the two technologies so that an image sensor would have the advantages of both. For example, U.S. Patent No. 5,625,210 purports to combine commonly used pinned photodiode technology from CCD image sensors with CMOS controlled circuitry.

[0004] The present invention combines aspects of CCD technology into a CMOS image sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Figure 1 is a schematic diagram of a prior art three transistor active pixel used in a CMOS image sensor.

[0006] Figure 2 is a schematic diagram of a prior art four transistor active pixel used in a CMOS image sensor.

[0007] Figure 3 is a schematic diagram of an active pixel formed in accordance with the present invention.

[0008] Figure 4 is a cross sectional view of a portion of the active pixel of Figure 3.

[0009] Figure 5 is a schematic diagram of an alternative embodiment of the present invention showing the use of shared transistors.

[0010] Figure 6 shows schematic and cross sectional views of yet another alternative embodiment utilizing an additional memory gate.

[0011] Figure 7 shows schematic and cross sectional views of yet another alternative embodiment utilizing a p-type layer underneath the memory gate and an additional control gate.

DETAILED DESCRIPTION

[0012] In the following description, numerous specific details are provided to provide a thorough understanding of embodiments of the invention. One skilled in the relevant art will recognize, however, that the invention can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the invention.

[0013] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

[0014] The present invention combines certain aspects of CCD technology with CMOS process technology. Figure 1 illustrates a prior art CMOS active pixel that uses three transistors. A light sensing element 101 outputs a signal that is used to modulate an amplification transistor 105. The amplification transistor is also known as a source-follower transistor. The light sensing element 101 can be one of a variety of devices, including without limitation, photogates, photodiodes, pinned photodiodes, partially pinned photodiodes, etc.

[0015] During an integration period, the light sensing element 101 captures light and outputs a signal indicative of the amount of light incident onto that light sensing element 101. The signal is used to modulate the amplification transistor 105. After the integration period, a reset transistor 103 is used to reset the level of the light sensing element output node to a reference level. Finally, a row select transistor 107 is used as a means to address the pixel and to selectively read out the signal from the pixel onto a column bit line 109.

[0016] Figure 2 is similar in many respects to the three transistor active pixel of Figure 1, except that an additional transfer transistor 201 is used to transfer the signal output by the light sensing element 101 to a floating node A. Although a four transistor active pixel may be larger in size because of the transfer gate 201, advantages relative to the three transistor active pixel of Figure 1 are still gained.

[0017] Turning to Figure 3, an active pixel formed in accordance with the present invention is shown. In this active pixel, a light sensing element 101 (which includes without limitation photogates, photodiodes, pinned photodiodes (sub-species of photodiodes), partially pinned photodiodes (sub-species of

photodiodes), and the like) has its signal transferred out to a sense node A by means of three gates: a transfer gate 301, a memory gate 303, and a control gate 305.

[0018] Once the signal from the light sensing element 101 is at the sense node A, the circuitry is similar to the prior art and includes a reset transistor 307, an amplification transistor 309, and a row select transistor 311. The signal on sense node A modulates the amplification transistor 309 such that the appropriate amplified signal is placed onto a column bit line 313. The row select transistor 311 is utilized to selectively address the active pixel in this embodiment.

[0019] By including the memory gate 303 and the control gate 305, each active pixel can incorporate memory in an analogous manner to CCD image sensors. In particular, once an integration period is completed by the light sensing element 101, both the transfer gate 301 and the memory gate 303 are activated. Specifically, a voltage (V_{on}) is applied to the transfer and memory gates 301 and 303. Note that the voltage V_{on} is a positive voltage for a p-type substrate. For an n-type substrate, V_{on} is a negative voltage. Further, the precise magnitude of V_{on} is a voltage that is determined by various design parameters of the pixel, but typically will be derived from V_{dd} or V_{cc} .

[0020] The application of V_{on} to the transfer and memory gates 301 and 303 will form a potential well (memory well 401) underneath the memory gate 303. Further, by applying a voltage to the transfer gate 301, charge (signal) generated by the light sensing element 101 will flow to the memory well 401 underneath the memory gate 303.

[0021] The memory gate 303 can then be held at voltage V_{on} while the transfer gate 301 returns to a quiescent voltage (either 0 volts or some fixed bias voltage). This will result in the signal from the light sensing element 101 being held in the memory well 401. In order to transfer the charge from the memory well 401 to the sense node A, the control gate 305 is then activated to V_{on} while the memory gate 303 returns to the quiescent state. This will result in transferring the signal from the memory well 401 to the sense node A. This is also under the control of both the control gate 305 and the memory gate 303.

[0022] Once the signal from the light sensing element 101 has been placed onto the sense node A, operation of the active pixel is similar to that of Figures 1 and 2. In other words, the signal on the sense node A is periodically reset using the reset transistor 307. Further, the signal on the sense node is used to modulate the amplification transistor 309 to output a amplified signal onto the column bitline 313. The row select transistor 311 is used to selectively address the pixel.

[0023] Figure 4 shows a cross section view of a semiconductor substrate showing the light sensing element 101 (in this case a photodiode), the transfer gate 301, the memory gate 303, the control gate 305, and the memory well 401. The transfer gate 301, memory gate 303, and control gate 305 are separated from the semiconductor substrate by a gate dielectric, such as a thin gate oxide. Also shown is the sensing node A. The transfer gate 301 is adjacent to the light sensing element 101. The term adjacent as used herein includes non-overlapping, overlapping, and aligned and may vary with different design

parameters. In any event, the transfer gate 301 should be disposed in a position to facilitate transfer of charge out of the light sensing element 101.

[0024] It can be appreciated that what is shown in Figures 3 and 4 is but one pixel in an array of pixels that form an image sensor. In many embodiments, the number of pixels in the image sensor array can range from hundreds of pixels to millions of pixels. Typically, the image sensor array has many pixels arranged as rows and columns. However, the present invention is directed towards the internal structure of a single pixel, and that pixel can be utilized in a variety of architectures.

[0025] Thus, as seen in Figure 4, a signal (represented as electrons) generated by the light sensing element 101 can be transferred by activating the transfer gate 301 and memory gate 303. This transfer allows the signal to move from the N-well of a photodiode comprising the light sensing element 101 into the memory well 401. The memory gate 303 and control gate 305 can then be controlled such that the signal is either stored within the memory well 401 or transferred to the sense node A. For example, the control transistor 305 can be activated at the desired time to have the signal read out from the memory well 401 into the sense node A.

[0026] The inclusion of the memory well 401 and the structure of the pixels of the present invention provide the ability to support "frame exposure." In other words, the image sensor using the present active pixels can expose the entire array to incident light and store the entire image (the frame) in the memory wells 401. This is in contrast to the conventional raster scanning readout techniques of many

prior art image sensors. Moreover, with appropriate process design, the memory well 401 can store the signal captured by the light sensing element 101 for a relatively long period of time, thereby giving a long memory duration.

[0027] While there is an increase of gates in each active pixel, the amount of increase of gates can be mitigated by the used of shared transistor technology. In particular, as seen in Figure 5, two or more adjacent pixels can share a reset transistor and an amplification transistor. Thus, by appropriate timing of the read out process, two or more adjacent pixels can share transistors and the total number of transistors required to implement an imaging array can be reduced. Further details of this type of shared transistor architecture can be found in commonly owned and co-pending U.S. Patent Application Serial No. 10/771,839 entitled "CMOS IMAGE SENSOR USING SHARED TRANSISTORS BETWEEN PIXELS" filed on February 4, 2004, which is herein incorporated by reference.

[0028] Furthermore, additional embodiments are also seen in connection with Figures 6 and 7. While the embodiment of Figures 3 and 4 shows the basic invention concept, in that embodiment, the silicon surface beneath the memory gate 303 is depleted when holding signal charges. This depletion causes a relatively large leakage current from the silicon surface. The alternative embodiments described below reduce the amount of leakage current from the silicon surface.

[0029] Figure 6 illustrates in schematic form and cross section an alternative embodiment of the present invention. Similar to the previous embodiment, the transfer gate is provided adjacent to the photodiode. However, a memory gate 2 is provided in addition to memory gate 1 and the control gate between the transfer

gate and node A. Further, for ease of manufacturing, the first and second memory gates, the transfer gate, and the control gate are all formed from the same layer of polysilicon.

[0030] In operation, initially memory gate 1, memory gate 2 and the control gate are all turned on to reset all regions beneath these gates. Then, memory gate 1, memory gate 2 and control gate are turned off sequentially. The signal generated by the incident light in the photodiode is transferred to under the memory gate 1 through the transfer gate by turning on the transfer gate and memory gate. At this time, memory gate 2 is turned off. Then, the transfer gate is turned off. This results in the signal being held beneath the memory gate 1.

[0031] At a next step, the memory gate 2 is turned on as memory gate 1 is turned off. At this time, the signal is then held beneath memory gate 2.

[0032] Next, memory gate 1 is turned on as memory gate 2 is turned off. The signal is then transferred back to underneath memory gate 1. The signal is thus alternately transferred back and forth between memory gate 1 and memory gate 2. In one embodiment, the transfer back and forth is at 1000 Hertz or more. This transfer back and forth occurs until the signal charges are read out to the column bit-line through the source follower.

[0033] The embodiment of Figure 6 decreases leakage current from the silicon surface. Leakage current from silicon surface is believed to relate to slow surface states at the silicon surface. The slow surface states cannot commonly respond to more than 1000 Hertz driving. Thus, when memory gates 1 and 2 are switched on and off at more than 1kHz, leakage current from the silicon surface should not increase. Still, the present invention is not limited to switching at greater than 1000 Hertz and other mechanism may come into play that make the present invention advantageous at less than 1000 Hertz switching.

[0034] Figure 7 illustrates in schematic form and cross section the third embodiment of the present invention. This embodiment includes a memory gate, a first control gate 1 and a second control gate 2 between the transfer gate and node A.

[0035] Note that in this embodiment, a p-type layer covers the silicon surface beneath the memory gate to avoid leakage current from the silicon surface. The p-type layer can be formed using a conventional masking and implantation step. An n-channel is formed at a deeper region than the p-type layer beneath the memory gate and control gate.

[0036] In operation, the n-channel is reset by turning on the memory gate, control gate 1, and control gate 2. Then, control gate 2 is turned off, and memory gate and control gate 1 are turned on. Next, the memory gate is set to a quiescent voltage (0 or negative voltage) or floating. The n-channel potential is set by the potential beneath the control gate 1. Then, the signal charges from the photodiode are transferred to the memory gate and control gate 1 by turning on and off the transfer gate. Then, the control gate 1 is turned off. At this time, the signal charges are held at the n-channel region beneath the memory Gate.

[0037] Note that in yet another alternative embodiment, control gate 2 may be omitted. In such an embodiment, the structure is similar to that of Figure 3, except with the addition of the p-type layer and n-channel.

[0038] When the signal charges are to be read out, the potential beneath control gate 2 is set to some potential. Then, the potential beneath control gate 1 is set to a shallower potential than that of control gate 2 by applying voltage to control gate 1. Next, the memory gate is turned off. Signal charges are then transferred to node A through control gates 1 and 2. This architecture also decreases leakage current from the silicon surface. Since the silicon surface beneath the memory gate is not depleted by the p-type layer, leakage current from the silicon surface is small.

[0039] The description of the invention and its applications as set forth herein is illustrative and is not intended to limit the scope of the invention. Variations and modifications of the embodiments disclosed herein are possible, and practical alternatives to, or equivalents of the various elements, of the embodiments are known to those of ordinary skill in the art. Further, the various doping types may be reversed, such that an n-channel transistor described above may be replaced

with a p-channel transistor. These and other variations and modifications of the embodiments disclosed herein may be made without departing from the scope and spirit of the invention.